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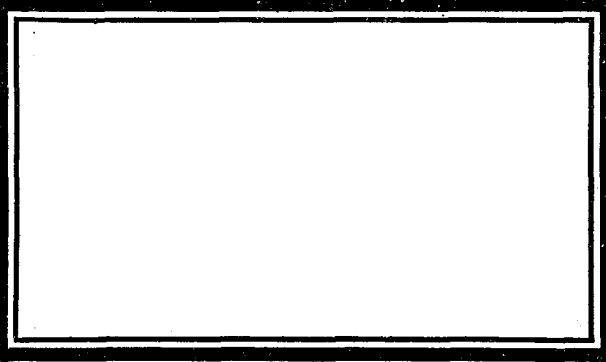
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**Puget Sound Naval Shipyard
Bremerton, Washington**

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LIGHTWEIGHT REINFORCED PLASTIC
FACED SANDWICH CONSTRUCTION
(S-R007-03-04) Task 1008

Report P-565

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ABSTRACT

The values of impact and flexure properties of sandwich panels with polyurethane foam and balsa wood cores with laminated glass-resin faces are shown.

SUMMARY PAGE

THE PROBLEM

The stiffness, impact resistance, and strength to weight ratio of sandwich panels with laminated resin-glass faces and 6 lbs/ft³ polyurethane foam core were to be determined and compared with the values obtained with similar panels where 2 lbs/ft³ polyurethane foam core had been used. (Panel 4, reference (b)). In addition, these properties were to be determined on end grain (grain parallel to panel thickness) balsa panels and compared to similar panels in which the end grain was perpendicular to the panel thickness (panel 3, reference (b)).

THE FINDINGS

The use of 6 lbs/ft³ urethane foam instead of 2 lbs/ft³ urethane for the core of a sandwich panel similar to Panel 4 of reference (b) caused the following property changes:

- (1) The unit weight of the panel was increased approximately 16%.
- (2) The stiffness factor was increased approximately 300%.
- (3) The ultimate load sustaining capacity was increased 500-700%.
- (4) The impact resistance was increased approximately 1,000%.
- (5) The stiffness factor expressed as a per cent of that of a beam of aluminum, steel, or teak of equal weight and thickness, was increased approximately 300%.

SUMMARY PAGE (Cont'd)

The use of end grain balsa (with the grain parallel to the panel thickness) in the core of a sandwich panel similar to Panel 3 of reference (b) did not change the unit weight of the panel. But the following changes in properties did occur:

- (1) The stiffness factor was increased approximately 30%.
- (2) The ultimate load sustaining capacity was increased approximately 100%.
- (3) The impact resistance was increased approximately 1,000%.
- (4) The stiffness factor, expressed as a per cent of that of a beam of aluminum, steel, or teak of equal weight and thickness, was increased approximately 30% in one direction and reduced approximately 30% in the other direction.

ADMINISTRATIVE INFORMATION

Ref: (a) BUSHIPS ltr 4120/5510 ser 634C3-840 of 18 Sep 1962
(b) NAVSHIPYDEREM MAT LABS Final Report P-505-3 of May 1962
(c) NAVSHIPYDEREM MAT LABS Progress Report P-505-1 of Oct 1960
(d) 1961 ASTM Standards, Part 5

Reference (a) authorized this Laboratory to determine the properties of sandwich panels similar to those of Panels 3 and 4 from reference (b).

Reference (c) contained a description of the impact test used to determine the impact resistance of the panels prepared for this investigation.

Reference (d) contained a description of the flexure test used in this investigation.

The Navy Identification Number for this investigation is 35-5510-1. Local Test Number P-565 has been assigned to this investigation.

REPORT OF INVESTIGATIONINTRODUCTION

Reference (a) authorized this Laboratory to determine the rigidity and impact strength of sandwich panels identical, except for the core structure, to Panels 3 and 4 of reference (b). For this phase of the investigation, nominal 6 lbs/ft³ polyurethane foam was substituted for the nominal 2 lbs/ft³ polyurethane foam used in Panel 4 of reference (b); and laminated balsa with the grain parallel to the thickness of the panel was substituted for the balsa core with the grain perpendicular to the panel thickness used in Panel 3, reference (b).

Except for the substitutions of core materials, the preparation and testing of the present series of sandwich panels was identical to that of Panels 3 and 4 of reference (b). Thus a comparison of the properties of the present sets of sandwich panels with those previously reported, can be used to determine the effects of the core material substitutions.

SANDWICH PANEL FABRICATION

Two sets of sandwich panels were made. The first set of 3 panels had cores of nominal 6 lbs/ft³, hand poured, polyurethane foam, contained three pieces of polyurethane foam, 9 inches by 27 inches by 1 inch thick, glued together to form three 27 inch square by one inch thick cores. The adhesive used to cement this foam together was formulated as shown in TABLE I.

TABLE I

FOAM CORE ADHESIVE

| <u>Material</u> | <u>Parts by Weight</u> |
|-------------------|------------------------|
| Polyester Resin 1 | 100 |
| Accelerator N | 1.0 |
| MEK Peroxide | 1.0 |
| Powdered Mica | 33.3 |

The second set of panels had balsa wood cores. Each of these three panels was composed of 3 inch square, nominal 10 lbs/ft³, pieces of balsa wood glued together to form three 27 inch square, one inch thick. In these panels the end grain of the balsa was parallel to the one inch dimension. Adhesive 1 was used to glue the balsa wood together.

The skins of the newest balsa wood and the polyurethane panels were identical to each other and to those of Panels 3 and 4 of reference (b). Thus, the top laminate of all of these panels consisted of Polyester Resin 1, formulated as shown in TABLE II, reinforced with three layers of woven roving (MIL-C-19663, Style 605-604 Volan A Finish) between an outer and inner ply of .010 inch thick asbestos mat. The bottom laminate consisted of the same polyester resin formulation reinforced with only two layers of woven roving and no asbestos mat.

TABLE II

LAMINATING RESIN FORMULATION

| <u>Material</u> | <u>Parts by Weight</u> |
|-------------------|------------------------|
| Polyester Resin 1 | 100 |
| Accelerator N | 0.5 |
| MEK Peroxide | 0.5 |

To fabricate the skins, the roving was first impregnated with resin and allowed to soak for approximately three hours prior to use. Then a wetting coat of resin was applied to the core followed by squeegeeing of each ply of reinforcement. After the skin was in place, "Mylar" film was placed over the liquid laminating resin and a plywood platen was placed on top of the "Mylar" film. Finally, sufficient weight was placed on the plywood to give a load of 0.3 lb/in^2 to insure a smooth and uniform laminated skin.

Core density, panel weight per square foot, and the calculated per cent of glass plus asbestos in the laminate for each of the six sandwich panels are listed in TABLE III.

TABLE III

CORE DENSITY, PANEL WEIGHT PER SQUARE FOOT,
AND PER CENT OF REINFORCEMENT IN SKIN

| <u>Panel No.</u> | <u>Core</u> | <u>Core Density, Lbs/ft³</u> | <u>Panel, Weight, Lbs/ft²</u> | <u>Per cent of Glass and Asbestos in Laminate</u> |
|------------------|---------------|---|--|---|
| 1 | Urethane Foam | 6.54 | 2.64 | 46.0 |
| 2 | Urethane Foam | 6.54 | 2.51 | 49.0 |
| 3 | Urethane Foam | 6.70 | 2.62 | 46.7 |
| 4 | Balsa Wood | 10.3 | 3.02 | 44.5 |
| 5 | Balsa Wood | 10.3 | 2.82 | 49.2 |
| 6 | Balsa Wood | 10.3 | 2.80 | 49.7 |

IMPACT AND FLEXURE TESTS

Samples from each of the six panels were subjected to both impact and flexure tests.

Test specimens for the impact test were 18 inches square. These specimens were subjected to the same falling ram impact test that was

described in reference (c). The method of conducting the impact test was identical to that described in reference (b), except that a heavier ram was used on two of the balsa wood panels. The high impact strength of these latter two panels necessitated the change in rams.

The flexure test specimens were 24 inches long, 3 inches wide and approximately 1.2 inches thick. Two specimens, whose lengths were perpendicular to each other on the original panel, were taken from each of the six sandwich panels.

The flexural properties of these beams were determined in accordance with the procedures given in ASTM Test Method C-393-61T (Flexure Test of Flat Sandwich Constructions) of reference (d) for 1/4 point loading.

The beams were placed on the test jig with the heavier face in compression. Load-deflection readings and ultimate load prior to failure were recorded for each of the twelve beams.

RESULTS

a. Impact Tests

The data recorded for the impact tests on each of the six panels are shown in Tables A-I through A-VI of Appendix A. This same data is shown graphically in Figures 1 through 6. On these graphs, the ratio of rebound energy to impact energy has been plotted against impact energy. For the polyurethane foam core panels (Figures 1 through 3), every recorded point was plotted. For the balsa wood cored panels (Figures 4 through 6), only those point necessary to outline the curves were plotted to prevent overlapping on these figures.

Although the curves in the six figures were not smooth, the general pattern was a curve whose slope approached infinity until an abrupt and significant change in the slope occurred. The point of discontinuity is indicated in each of the six figures and corresponds fairly closely with a point of significant increase in the observed damage to each panel. In practical terms, this point of discontinuity can be defined as the point at which the panel no longer reacted to the blow as a homogeneous unit. Therefore, this point of discontinuity was used to indicate the impact strength of these panels. The impact energy at the point of discontinuity taken from each of the six figures is shown in Column 8 of TABLE IV.

b. Flexure Tests

The data derived from the flexure tests of beams cut at right angles to each other on each of the sandwich panels, is also summarized in TABLE IV. In this Table, Columns 1 and 2 contain, respectively, the identification of the sandwich panel and the core material. Column 3 contains the load range in which the stiffness factors in Columns 4 and 5 were calculated. Columns 6 and 7 contain the highest load recorded prior to failure of each of the beams. As previously stated, Column 8 contains the impact strength for each of the panels. The last column, Column 9, contains the unit weight in lbs/ft^2 of the completed panels.

The stiffness factor, listed in Columns 4 and 5, is a measure of the rigidity of a beam and it is equal to the slope of the load-deflection curve within the load range indicated.

In TABLE IV, values for the stiffness factor and the ultimate load are presented for both the weakest and the strongest direction. It was assumed that the weakest beams would be those whose length was parallel to the 4 strands of the 4 by 5 weave of the woven roving. However, other variations in some panels resulted in strength properties not related to directional properties of the glass reinforcement.

EVALUATION OF RESULTS

a. Polyurethane Foam Core Panels

A comparison of the properties of Panel #4 from reference (b) with those of the averages of the present Panels 1, 2, and 3 indicates that the substitution of 6 lbs/ft³ foam for 2 lbs/ft³ foam produced the following changes:

- (1) Based on the data in Column 9 of TABLE IV the weight per square foot was increased about 16%.
- (2) The stiffness factor in both the weakest and strongest direction was approximately tripled as indicated by the data in Columns 4 and 5.
- (3) The ultimate load was increased approximately six times in each direction as indicated by the data in Columns 6 and 7.
- (4) The impact resistance was increased approximately ten times. Thus, with only a small increase in overall weight, the strength properties of this group of panels was greatly improved by using 6 lbs/ft³ foam in place of the 2 lbs/ft³ foam.

TABLE IV
STIFFNESS FACTORS, ULTIMATE LOADS, IMPACT STRENGTH AND UNIT WEIGHT OF SANDWICH PANELS

| Sandwich Panel (1) | Core Material (2) | Load Range For Stiffness Factors or Calculation, Lbs. (3) | Stiffness Factor, Lbs./In. (4) | Stiffness Factor, Strongest Direction (5) | Ultimate Load, Lbs. Weakest Direction (6) | Ultimate Load, Strongest Direction (7) | Impact Strength, In-Lbs (8) | Unit Weight of Sandwich Panel, Lbs./ft ² (9) |
|--------------------|---------------------------|---|--------------------------------|---|---|--|-----------------------------|---|
| 1 | 6Lbs/ft ³ Foam | 0-360 | 1820 | 1740 | 826 | 824 | 480(a) | 2.64 |
| 2 | " " | 0-360 | 1465 | 1700 | 701 | 814 | 288 | 2.51 |
| 3 | " " | 0-360 | 1790 | 1840 | 826 | 841 | 320 | 2.62 |
| Average 1,2,3 | " " | 0-360 | 1690 | 1760 | 784 | 826 | 304 | 2.59 |
| 4(b) | 2Lbs/ft ³ Foam | 0-60 | 550 | 582 | 126 | 146 | 32 | 2.23 |
| 4 | Balsa Wood | 0-600 | 3280 | 3720 | 2301 | 1601 | 2160 | 3.02 |
| 5 | " " | 0-600 | 3350 | 3220 | 1191 | 1196 | 3250 | 2.82 |
| 6 | " " | 0-600 | 3530 | 3470 | 1670 | 2191 | 3250 | 2.80 |
| Average 4,5,6 | " " | 0-600 | 3390 | 3470 | 1721 | 1663 | 2890 | 2.88 |
| 3(b) | " " | (c) | 2600 | 5140 | 708 | 962 | 320 | 2.84 |

NOTE:

- (a) This value was not used to calculate the average impact strength for these Panels (1, 2, and 3) because there was a possible point of discontinuity in Figure 1, lower than the one used.
 (b) From reference (b).
 (c) Load range varied from 0-350-to 9-900 lbs.

A comparison of the stiffness factor of both the 6 lbs/ft³ and the 2 lbs/ft³ from cored beams is shown in TABLE V. In this Table, the stiffness factor of both types of foam beams are expressed as a per cent of the stiffness factors of aluminum, steel, and teak beams of equal weight and thickness to those of the foam cured panels assuming the span and method of loading to be identical. The data in this Table indicates that the average stiffness factor for the 6 lbs/ft³ foam cored beams was approximately 30% of that of the aluminum, steel, and teak as compared to approximately 10% for 2 lbs/ft³ foam.

b. Balsa Wood Core Panels

For the balsa wood core beams the substitution of a core with the end grain of the wood running parallel to thickness instead of perpendicular to the thickness resulted in the following changes in properties:

- (1) As might be expected, the weight per square foot was increased negligibly.
- (2) The anisotropy of the panel was virtually eliminated resulting in a stiffness factor somewhat higher than that for Panel 3 (reference (b)) in one direction, and somewhat lower than that reported for Panel No. 3 in the other direction.
- (3) An ultimate load approximately twice as great.
- (4) Impact strength of at least nine times as great.

A comparison between the stiffness of similar beams of aluminum, steel, and teak and that of both the end grain balsa wood cored beams and

of Panel 3, reference (b), is made in TABLE V. The data in this Table shows that beams of end grain balsa had a stiffness factor of approximately 50% of those for aluminum steel and teak compared to approximately 40% for Panel 3, reference (b), in the weakest direction. In the strongest direction, the substitution of end grain balsa reduced the stiffness factor from approximately 80% of that for the aluminum, steel, and teak to approximately 50%.

CONCLUSIONS

The use of 6 lbs/ft³ urethane foam instead of 2 lbs/ft³ urethane for the core of a sandwich panel similar to Panel 4 of reference (b) caused the following property changes:

- (1) The unit weight of the panel was increased approximately 16%.
- (2) The stiffness factor was increased approximately 300%.
- (3) The ultimate load sustaining capacity was increased 500-700%.
- (4) The impact resistance was increased approximately 1,000%.
- (5) The stiffness factor expressed as a per cent of that of a beam of aluminum, steel, or teak of equal weight and thickness, was increased approximately 300%.

The use of end grain balsa (with the grain parallel to the panel thickness) in the core of a sandwich panel similar to Panel 3 of reference (b) did not change the unit weight of the panel. But the following changes in properties did occur:

- (1) The stiffness factor was increased approximately 30%.
- (2) The ultimate load sustaining capacity was increased approximately 100%.
- (3) The impact resistance was increased approximately 1,000%

4. The stiffness factor, expressed as a per cent of that of a beam of aluminum, steel, or teak of equal weight and thickness, was increased approximately 30% in one direction and reduced approximately 30% in the other direction.

TABLE V
AVERAGE STIFFNESS FACTORS OF SANDWICH PANELS EXPRESSED AS PER CENT OF
THE STIFFNESS OF THREE MATERIALS

| Sandwich Panel Identification | Core Material | Average Stiffness Factor of Assumed Weakest Beams Divided by the Stiffness Factor of a Comparable Beam of Aluminum, Steel, or Teak | | | Average Stiffness Factor of Assumed Strongest Beams Divided by the Stiffness Factor of a Comparable Beam of Aluminum, Steel, or Teak | | |
|----------------------------------|-------------------------------|---|------------------|-----------------|---|------------------|-----------------|
| | | Aluminum Beam, % | Steel Beam, % | Teak Beam, % | Aluminum Beam, % | Steel Beam, % | Teak Beam, % |
| Panel #4 (a) | 2 lbs/ft ³ Foam | 10.2 | 11.1 | 11.3(b) | 10.8 | 11.7(b) | 12.0(b) |
| Average of Panels 1, 2, & 3 | 6 lbs/ft ³ Foam | 27.5 | 30.0 | 30.6 | 28.7 | 31.2 | 31.9 |
| Panel #3 (a) | Balsa Wood | 38.7 | 42.4 | 43.0(b) | 76.4 | 83.0(b) | 84.8(b) |
| Average of Panels 4, 5, & 6 | Balsa Wood | 50.5 | 54.9 | 56.1 | 51.7 | 56.2 | 57.4 |

NOTES:

- (a) From reference (b)
(b) These are revised figures.

Figure 1

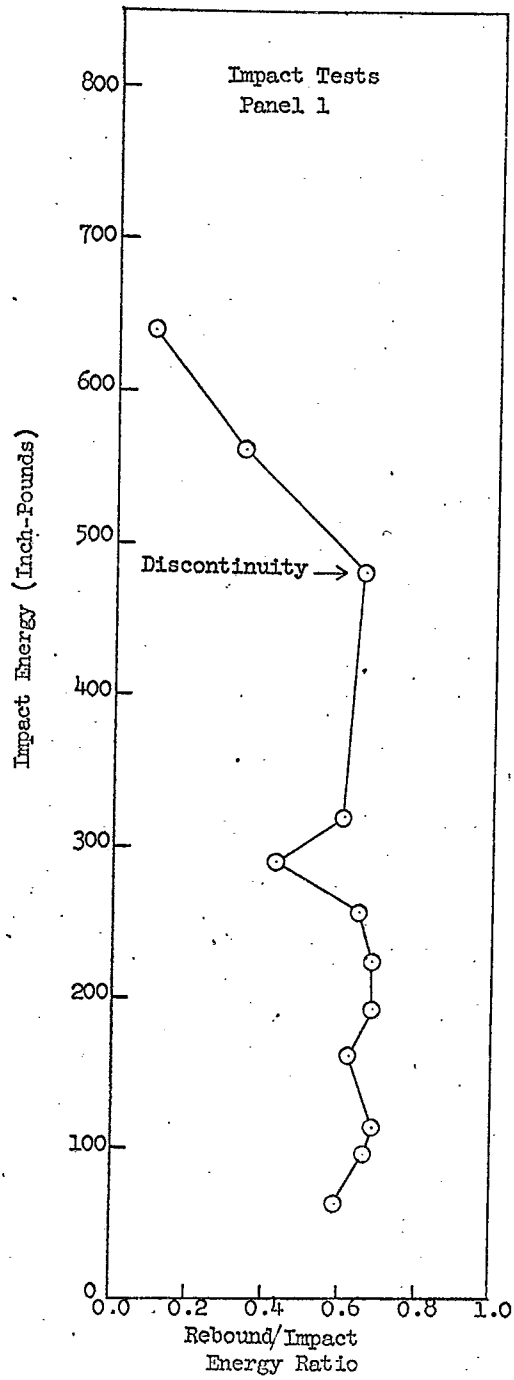


Figure 2

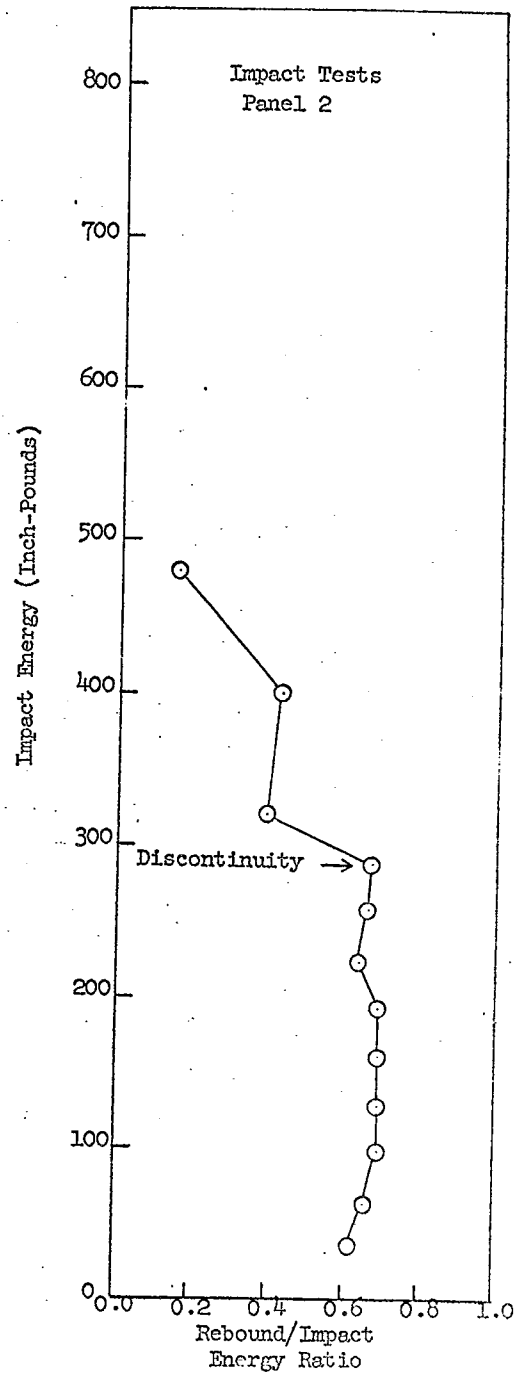


Figure 3

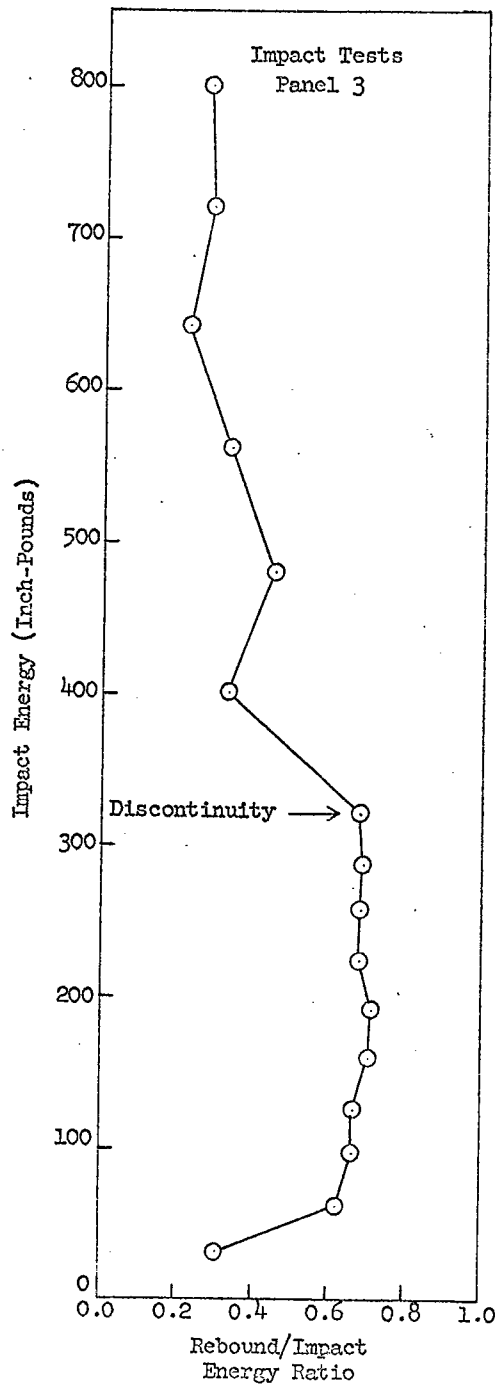


Figure 4

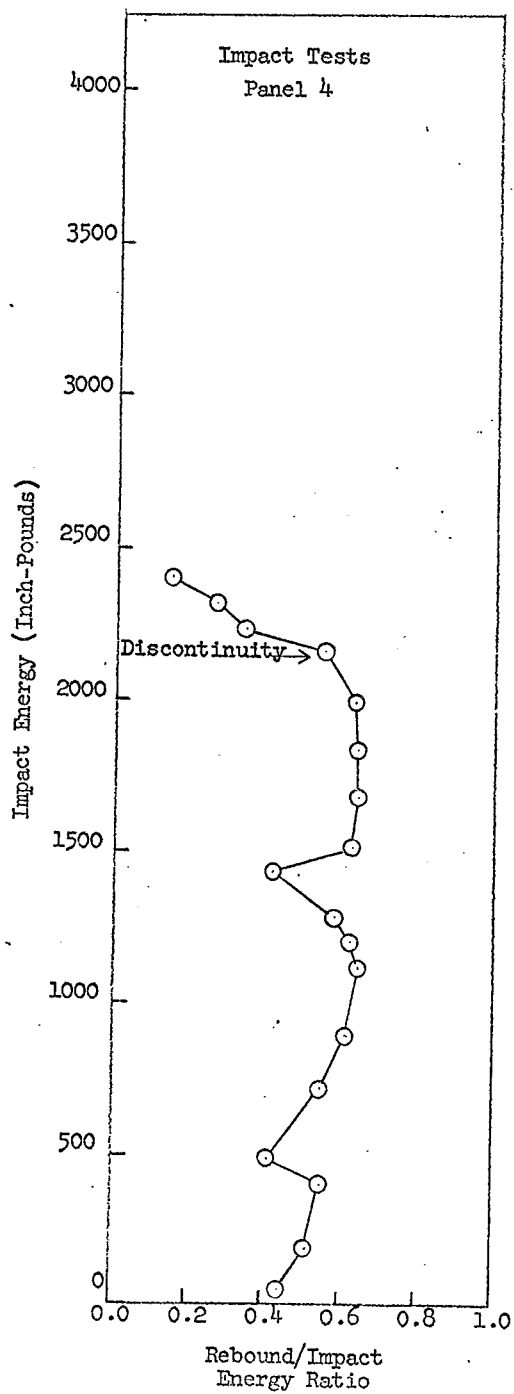


Figure 5

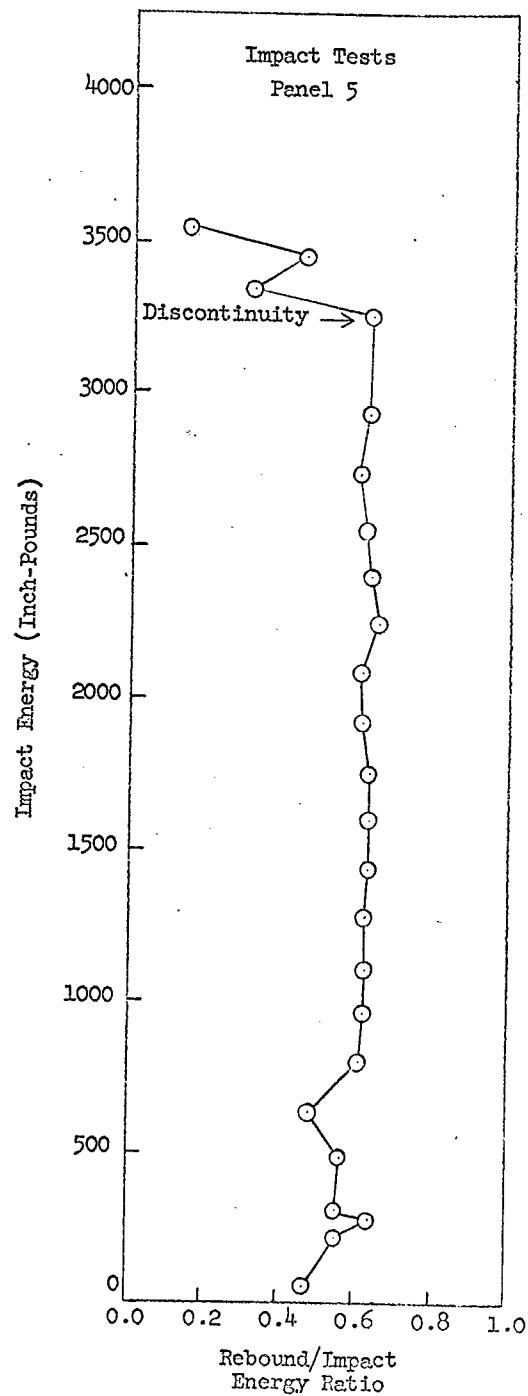
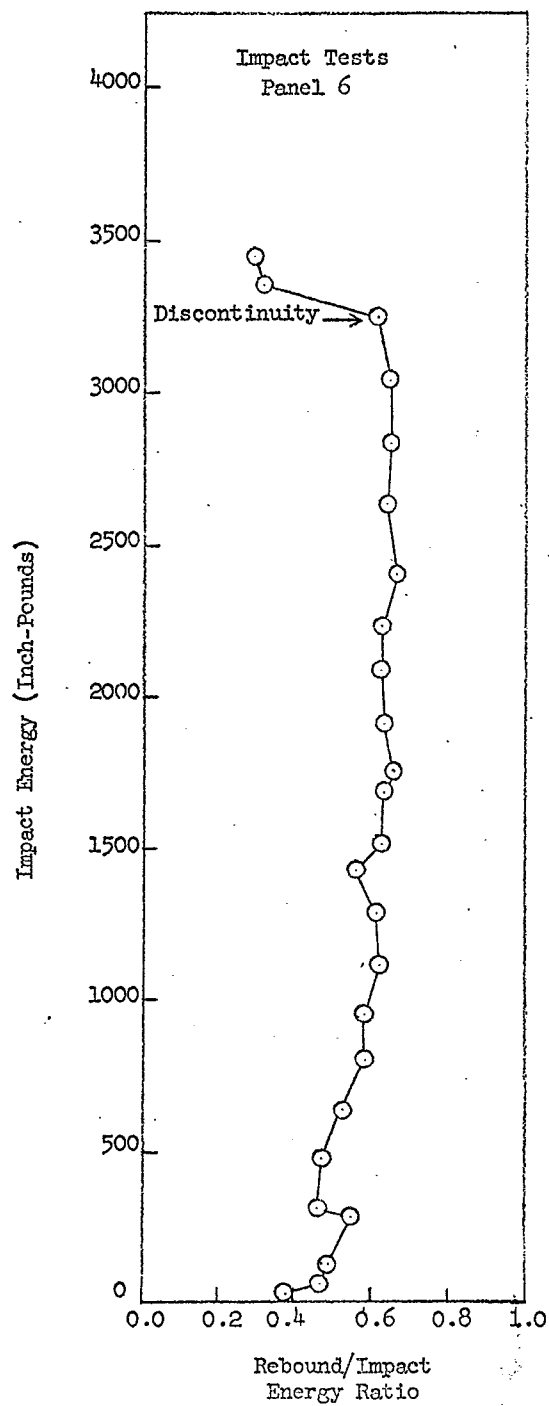


Figure 6



APPENDIX A
TABLE A-I

Sandwich Panel #1--Polyurethane Foam Core

Impact Test: Ram Drop Height, Impact Energy and Rebound/Impact
Energy Ratio

| <u>Drop Number</u> | <u>Drop Height, Inches</u> | <u>Impact Energy Inch-Pounds</u> | <u>Rebound/Impact Energy Ratio</u> |
|------------------------|--------------------------------|--------------------------------------|--|
| 1 | 2 | 32 | - - |
| 2 | 4 | 64 | 0.594 |
| 3 | 6 | 96 | 0.657 |
| 4 | 8 | 128 | 0.689 |
| 5 | 10 | 160 | 0.625 |
| 6 | 12 | 192 | 0.688 |
| 7 | 14 | 224 | 0.678 |
| 8 | 16 | 256 | 0.648 |
| 9 | 18 | 288 | 0.430 |
| 10 | 20 | 320 | 0.500 |
| 11 | 25 | 400 | - - |
| 12 | 30 | 480 | 0.555 |
| 13 | 35 | 560 | 0.336 |
| 14 | 40 | 640 | 0.097 |

REMARKS:

- Drop Number: 1. through 11 - No visible damage
 12. Upper skin crazed in impact area.
 13. Forty-five degree shear in core, partial delamination
 of lower skin.
 14. Partial delamination of upper skin.

APPENDIX A
TABLE A-II

Sandwich Panel #2--Polyurethane Foam Core

Impact Test: Ram Drop Height, Impact Energy and Rebound/Impact
Energy Ratio

| <u>Drop Number</u> | <u>Drop Height, Inches</u> | <u>Impact Energy Inch-Pounds</u> | <u>Rebound/Impact Energy Ratio</u> |
|------------------------|--------------------------------|--------------------------------------|--|
| 1 | 2 | 32 | 0.562 |
| 2 | 4 | 64 | 0.657 |
| 3 | 6 | 96 | 0.688 |
| 4 | 8 | 128 | 0.688 |
| 5 | 10 | 160 | 0.688 |
| 6 | 12 | 192 | 0.687 |
| 7 | 14 | 224 | 0.642 |
| 8 | 16 | 256 | 0.665 |
| 9 | 18 | 288 | 0.674 |
| 10 | 20 | 320 | 0.387 |
| 11 | 25 | 400 | 0.430 |
| 12 | 30 | 480 | 0.162 |

REMARKS:

Drop Number: 1 thru 8--No visible damage
 9. Slight crazing in upper facing.
 10 and 11--More crazing of plastic facing.
 12 Forty-five degree shear in core, partial delamination of
 upper and lower skins.

APPENDIX A
TABLE A-III

Sandwich Panel #3--Polyurethane Foam Core

Impact Test: Ram Drop Height, Impact Energy and Rebound/Impact
Energy Ratio

| <u>Drop Number</u> | <u>Drop Height, Inches</u> | <u>Impact Energy Inch-Pounds</u> | <u>Rebound/Impact Energy Ratio</u> |
|------------------------|--------------------------------|--------------------------------------|--|
| 1 | 2 | 32 | 0.313 |
| 2 | 4 | 64 | 0.625 |
| 3 | 6 | 96 | 0.670 |
| 4 | 8 | 128 | 0.672 |
| 5 | 10 | 160 | 0.706 |
| 6 | 12 | 192 | 0.710 |
| 7 | 14 | 224 | 0.678 |
| 8 | 16 | 256 | 0.679 |
| 9 | 18 | 288 | 0.687 |
| 10 | 20 | 320 | 0.676 |
| 11 | 25 | 400 | 0.330 |
| 12 | 30 | 480 | 0.430 |
| 13 | 35 | 560 | 0.335 |
| 14 | 40 | 640 | 0.225 |
| 15 | 45 | 720 | 0.278 |
| 16 | 50 | 800 | 0.275 |

REMARKS:

Drop Number: 1 thru 12--No visible damage.
 13 Forty-five degree shear in core. Bottom skin partially delaminated.
 14 More separation of core and bottom facing.
 15 Partial separation of upper facing and core.
 16 More separation of upper facing and core.

APPENDIX A

TABLE A-IV

Sandwich Panel #4--Balsa Wood CoreImpact Test: Ram Drop Height, Impact Energy, and Rebound/Impact
Energy Ratio

| <u>Drop Number</u> | <u>Drop Height, Inches</u> | <u>Impact Energy Inch Pounds</u> | <u>Rebound/Impact Energy Ratio</u> |
|------------------------|--------------------------------|--------------------------------------|--|
| 1 | 2 | 32 | 0.407 |
| 2 | 4 | 64 | 0.428 |
| 3 | 6 | 96 | 0.440 |
| 4 | 8 | 128 | 0.493 |
| 5 | 10 | 160 | 0.550 |
| 6 | 12 | 192 | 0.506 |
| 7 | 14 | 224 | 0.506 |
| 8 | 16 | 256 | 0.539 |
| 9 | 18 | 288 | 0.548 |
| 10 | 20 | 320 | 0.563 |
| 11 | 25 | 400 | 0.554 |
| 12 | 30 | 480 | 0.404 |
| 13 | 35 | 560 | 0.425 |
| 14 | 40 | 640 | 0.551 |
| 15 | 45 | 720 | 0.550 |
| 16 | 50 | 800 | 0.581 |
| 17 | 55 | 880 | 0.605 |
| 18 | 60 | 960 | - - - |
| 19 | 65 | 1040 | - - - |
| 20 | 70 | 1120 | 0.618 |
| 21 | 75 | 1200 | 0.616 |
| 22 | 80 | 1280 | 0.584 |
| 23 | 85 | 1360 | 0.635 |
| 24 | 90 | 1440 | 0.422 |
| 25 | 95 | 1520 | 0.630 |
| 26 | 100 | 1600 | 0.630 |
| 27 | 105 | 1600 | 0.643 |
| 28 | 110 | 1760 | 0.637 |
| 29 | 115 | 1840 | 0.637 |
| 30 | 120 | 1920 | 0.636 |
| 31 | 125 | 2000 | 0.627 |
| 32 | 130 | 2080 | 0.608 |
| 33 | 135 | 2160 | 0.546 |
| 34 | 140 | 2240 | 0.343 |
| 35 | 145 | 2320 | 0.261 |
| 36 | 150 | 2400 | 0.148 |

REMARKS: Drop Number-

- 1 thru 11--No visible damage
 12 Separation of both the upper and lower facing in impact area.
 13 thru 32--Extension of core-facing delamination towards edges of panel.
 33 Core-facing delamination reached edges of panel.
 34, 35 Vertical shearing of wood core.

APPENDIX A
TABLE A-V

Sandwich Panel #5 - Balsa Wood Core

Impact Test: Ram Drop Height, Impact Energy and Rebound/Impact
Energy Ratio

| <u>Drop Number</u> | <u>Drop Height, Inches</u> | <u>Impact Energy Inch-Pounds</u> | <u>Rebound/Impact Energy Ratio</u> |
|------------------------|--------------------------------|--------------------------------------|--|
| 1 | 2 | 32 | 0.442 |
| 2 | 4 | 64 | 0.500 |
| 3 | 6 | 96 | 0.531 |
| 4 | 8 | 128 | 0.538 |
| 5 | 10 | 160 | 0.542 |
| 6 | 12 | 192 | 0.554 |
| 7 | 14 | 224 | 0.547 |
| 8 | 16 | 256 | 0.641 |
| 9 | 18 | 288 | 0.550 |
| 10 | 20 | 320 | 0.565 |
| 11 | 25 | 400 | 0.572 |
| 12 | 30 | 480 | - - - |
| 13 | 35 | 560 | 0.475 |
| 14 | 40 | 640 | 0.556 |
| 15 | 45 | 720 | 0.605 |
| 16 | 50 | 800 | 0.596 |
| 17 | 55 | 880 | 0.613 |
| 18 | 60 | 960 | 0.629 |
| 19 | 65 | 1040 | 0.622 |
| 20 | 70 | 1120 | 0.600 |
| 21 | 75 | 1200 | 0.619 |
| 22 | 80 | 1280 | 0.630 |
| 23 | 85 | 1360 | 0.628 |
| 24 | 90 | 1440 | 0.615 |
| 25 | 95 | 1520 | 0.626 |
| 26 | 100 | 1600 | 0.627 |
| 27 | 105 | 1680 | 0.627 |
| 28 | 110 | 1760 | 0.606 |
| 29 | 115 | 1840 | 0.613 |
| 30 | 120 | 1920 | 0.610 |
| 31 | 125 | 2000 | 0.612 |
| 32 | 130 | 2080 | 0.618 |
| 33 | 135 | 2160 | 0.629 |
| 34 | 140 | 2240 | 0.636 |
| 35 | 145 | 2320 | 0.628 |
| 36 | 150 | 2400 | 0.625 |
| 37 | 150 | 2400 | 0.627 |
| 38 | 150 | 2400 | |

APPENDIX A
TABLE A-V (Cont'd)

| <u>Drop Number</u> | <u>Drop Height, Inches</u> | <u>Impact Energy, Inch-Pounds</u> | <u>Rebound/Impact Energy Ratio</u> |
|------------------------|--------------------------------|---------------------------------------|--|
| 39 | 150 | 2400 | 0.622 |
| 40 | 150 | 2400 | 0.648 |
| 41 | 150 | 2400 | 0.648 |
| 42 | 150 | 2400 | 0.635 |
| 43 | 150 | 2400 | 0.625 |
| 44 | 150 | 2400 | 0.625 |
| 45 | 150 | 2400 | 0.641 |
| 46 | 50 | 2540 | 0.606 |
| 47 | 52 | 2640 | - - - |
| 48 | 54 | 2740 | 0.597 |
| 49 | 56 | 2840 | 0.597 |
| 50 | 58 | 2940 | 0.624 |
| 51 | 60 | 3040 | 0.637 |
| 52 | 62 | 3150 | 0.631 |
| 53 | 64 | 3250 | 0.625 |
| 54 | 66 | 3350 | 0.307 |
| 55 | 68 | 3450 | 0.450 |
| 56 | 70 | 3550 | 0.152 |

REMARKS:

Drop Number:

- 1 thru 7--No visible damage.
 8 Separation of top and bottom facings from core in impact area.
 9 thru 53 Extension of core-facing separation towards edges of panel.
 54 Upper facing buckled half way across panel.
 55 No further damage.
 56 Vertical shear in core and upper face buckled all of the way across panel.

APPENDIX A
TABLE A-VI

Sandwich Panel #6--Balsa Wood Core

Impact Test: Ram Drop Height, Impact Energy and Rebound/Impact
Energy Ratio

| <u>Drop Number</u> | <u>Drop Height, Inches</u> | <u>Impact Energy Inch-Pounds</u> | <u>Rebound/Impact Energy Ratio</u> |
|------------------------|--------------------------------|--------------------------------------|--|
| 1 | 2 | 32 | 0.375 |
| 2 | 4 | 64 | 0.409 |
| 3 | 6 | 96 | 0.459 |
| 4 | 8 | 128 | 0.485 |
| 5 | 10 | 160 | 0.488 |
| 6 | 12 | 192 | 0.520 |
| 7 | 14 | 224 | 0.491 |
| 8 | 16 | 256 | 0.554 |
| 9 | 18 | 288 | 0.550 |
| 10 | 20 | 320 | 0.463 |
| 11 | 25 | 400 | 0.454 |
| 12 | 30 | 480 | 0.466 |
| 13 | 35 | 560 | 0.490 |
| 14 | 40 | 640 | 0.525 |
| 15 | 45 | 720 | 0.563 |
| 16 | 50 | 800 | 0.579 |
| 17 | 55 | 880 | 0.584 |
| 18 | 60 | 960 | 0.580 |
| 19 | 65 | 1040 | 0.604 |
| 20 | 70 | 1120 | 0.617 |
| 21 | 75 | 1200 | 0.603 |
| 22 | 80 | 1280 | 0.614 |
| 23 | 85 | 1360 | 0.587 |
| 24 | 90 | 1440 | 0.565 |
| 25 | 95 | 1520 | 0.623 |
| 26 | 100 | 1600 | 0.645 |
| 27 | 105 | 1680 | 0.631 |
| 28 | 110 | 1760 | 0.650 |
| 29 | 115 | 1840 | 0.639 |
| 30 | 120 | 1920 | 0.634 |
| 31 | 125 | 2000 | 0.649 |
| 32 | 130 | 2080 | 0.620 |
| 33 | 135 | 2160 | 0.628 |
| 34 | 140 | 2240 | 0.637 |
| 35 | 145 | 2320 | 0.654 |
| 36 | 150 | 2400 | 0.655 |

APPENDIX A
TABLE A-VI (Cont'd)

| <u>Drop Number</u> | <u>Drop Height Inches</u> | <u>Impact Energy Inch-Pounds</u> | <u>Rebound/Impact Energy Ratio</u> |
|------------------------|-------------------------------|--------------------------------------|--|
| 37 | 150 | 2400 | 0.655 |
| 38 | 150 | 2400 | 0.661 |
| 39 | 150 | 2400 | 0.661 |
| 40 | 150 | 2400 | 0.647 |
| 41 | 150 | 2400 | 0.595 |
| 42 | 150 | 2400 | 0.670 |
| 43 | 150 | 2400 | 0.657 |
| 44 | 150 | 2400 | 0.646 |
| 45 | 150 | 2400 | 0.665 |
| 46 | 50 | 2540 | - - - |
| 47 | 52 | 2640 | 0.634 |
| 48 | 54 | 2740 | 0.654 |
| 49 | 56 | 2840 | 0.645 |
| 50 | 58 | 2940 | 0.647 |
| 51 | 60 | 3040 | 0.639 |
| 52 | 62 | 3150 | 0.643 |
| 53 | 64 | 3250 | 0.615 |
| 54 | 66 | 3350 | 0.307 |
| 55 | 68 | 3450 | 0.289 |

REMARKS:

Drop Number:

- 1 through 7--No visible damage.
 8 Separation of both top and bottom facing from core in impact area.
 9 through 53--Extension of core-facing separation towards edges of panel.
 54 Upper facing buckled half way across panel.
 55 Upper facing buckled all the way across panel, vertical shear in panel core.

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